

Optical System Design of the Mars Observer Laser Altimeter

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ABSTRACT

A diode-pumped, 40 mJ per pulse, laser is the basis of the Mars Observer Laser Altimeter. The optical system features a beryllium optical bench, 0.5 m diameter telescope, and a silicon avalanche photodiode receiver. Design rationale and measured optical performance are provided.

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An altimeter instrument based on a diode-pumped solid-state pulsed laser has been developed for flight on the Mars Observer Spacecraft in September 1992. The Mars Observer Laser Altimeter (MOLA) is designed to measure the topography of the Martian surface over a two-year period from a 400 km mapping orbit.

MOLA utilizes a pulsed laser transmitter and compact optical receiver to measure pulse time-of-flight and thus range to the surface at nadir at a rate of 10 pulses-per-second (pps). The optical system of MOLA consists of a diode-pumped Nd:YAG laser transmitter, optical bench, reflector telescope, bandpass and solar rejection optical filters, and a silicon avalanche photodiode (APD) detector. Operating wavelength of this system is the 1064 nm fundamental wavelength of the Nd:YAG laser. Optical components of MOLA are illustrated in the Fig. 1 in a cross-section view. The primary design constraints for these components are the severe mass and power budgets of Mars Observer, the 400 km range at nadir to the Martian surface, the required continuous operating lifetime of two years, launch vibration, and payload thermal environment on orbit.

A diode-pumped Nd:YAG laser capable of 40 mJ per pulse developed at McDonnell Douglas Electronic Systems Company (MDESC), St. Louis, was chosen as the basis of the optical system (ref. 1). This multimode slab laser produces 0.4 watt average optical power at 3% overall efficiency from the +28 vdc battery prime power of Mars Observer. The output laser pulse has a minimum laser pulsewidth of 7 nsec (FWHM) and is designed for 10 pps operation. Diode pumping by arrays of GaAlAs laser diodes at 808 nm wavelength is essential for efficient production of the 600 million laser pulses required for operational topographic mapping in the Mars Observer mission. The MDESC laser has demonstrated operation within 15% of full output pulse energy with passive cooling for a temperature range of 20°C about its optimum interface temperature of 0°C. The MOLA thermal design consists of passive radiators and 3 watts of supplemental heat to maintain a $\pm 7^\circ\text{C}$ temperature range over the expected diurnal variations in Mars orbit and the aphelion-to-perihelion thermal bias shift during the Martian year. Output laser divergence is controlled by a beam expander telescope inside the laser to produce a 0.5 mrad square cross-section beam that contains 90% of the pulse energy. This divergence produces a 200 m square altimeter sensor footprint on the Martian surface.

The receiver telescope is surplus flight hardware for the VOYAGER Infrared Imaging Spectrometer Instrument (ref. 2). This beryllium telescope is composed of a fast (f/0.8) 0.5 m diameter parabolic primary and a center-post mounted hyperbolic secondary mirror in a Cassegrain configuration. It has an effective focal length of 3035 mm and produces a 0.8 mm diameter blur circle for a point source at infinity. Since this blur circle is approximately 200 times the diffraction limit, the telescope serves as a "photon-bucket" for the altimeter application. The beryllium construction of this telescope and the extreme restrictions on payload mass drive the optical design toward use of beryllium for the optical bench and the laser case. The resultant all-beryllium composition of the transmitter and receiver optics are intended to maintain alignment in the payload testing and operational thermal environment.

In operation the 1064 nm laser radiation scattered from the Martian surface and collected by

the telescope is relayed through a collimating and focusing lens and two optical filters prior to detection by the silicon APD. The lenses are constructed of F2G12 radiation-resistant optical glass and are custom built for diffraction-limited image quality and maximum throughput at 1064 nm. Measured image quality for the combination of lenses and telescope at f/1.85 is a blur circle of 260 μm for a point source at infinity. Two optical filters, a 2.25 nm FWHM 3-cavity bandpass and a solar rejection filter, are located between the collimating and focusing relay optics. This combination provides an optical throughput of $> 65\%$ at 1064 nm over a temperature range of $\pm 15^\circ\text{C}$ about the 0°C nominal interface plate temperature of the optical bench and a blocking of $\geq 10^{-4}$ outside this bandpass from 200 nm to 1.2 μm . The solar rejection filter has metallic and dielectric coatings to provide reflection of out-of-band solar radiation and thus provide a temporary survival capability to the MOLA receiver for accidental viewing of the solar disk.

The silicon APD chosen for the MOLA detector is a **space-qualified** design by MDESC that is produced at RCA Canada. It exhibits a low excess noise factor of 2.5, a high **responsivity** $\geq 7.7 \times 10^5 \text{ V/Watt}$, and is **packaged into a hybrid** detector preamplifier configuration. The NEP for this hybrid is 250 pWatt for a 24 MHz bandpass. The silicon APD detector element is a dimpled structure with 40% quantum efficiency at 1064 nm at 30°C . Quantum efficiency at 1064 nm in silicon falls off rapidly with temperature. The housing of the lenses and filters is also the support for the detector package and is constructed of titanium, in part to provide a thermal barrier to heat flow from the detector package, and thus maintain its 30°C temperature and high quantum efficiency. The field-of-view of the silicon APD in the MOLA optical system is 0.85 mrad. This provides a misalignment margin of $\sim \pm 100 \text{ } \mu\text{rad}$ over the 0.6 mrad size of the MOLA laser footprint as degraded by the receiver telescope image quality.

Boresight alignment of the MOLA laser transmitter to the silicon APD detector is accomplished by a pentaprism and a pair of **Risley** prisms at the laser output. The pentaprism turns the laser output pulse through a right angle at the **periphery** of the telescope primary mirror; while the matched pair of **Risley prisms** provides 5 mrad of pointing angle adjustment by rotation of

circular prism wedges. A fiber optic cable and small focusing lens are located in the pentaprism housing to provide a sampling of the MOLA laser output pulse energy for the laser altimeter start-pulse functions. Once aligned during assembly and test, the design of the MOLA optical system is intended to maintain transmitter-to-receiver boresite alignment and an optical throughput of $\geq 50\%$ at 1064 nm over the launch vibration and on-orbit thermal environment of Mars Observer.

REFERENCES:

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MOLA OPTICAL ASSEMBLY

